Large Deformation Non-Linear Response of Composite Structures

C.C. Chamis
NASA Glenn Research Center
Cleveland, OH

L. Minnetyan
Clarkson University
Potsdam, NY

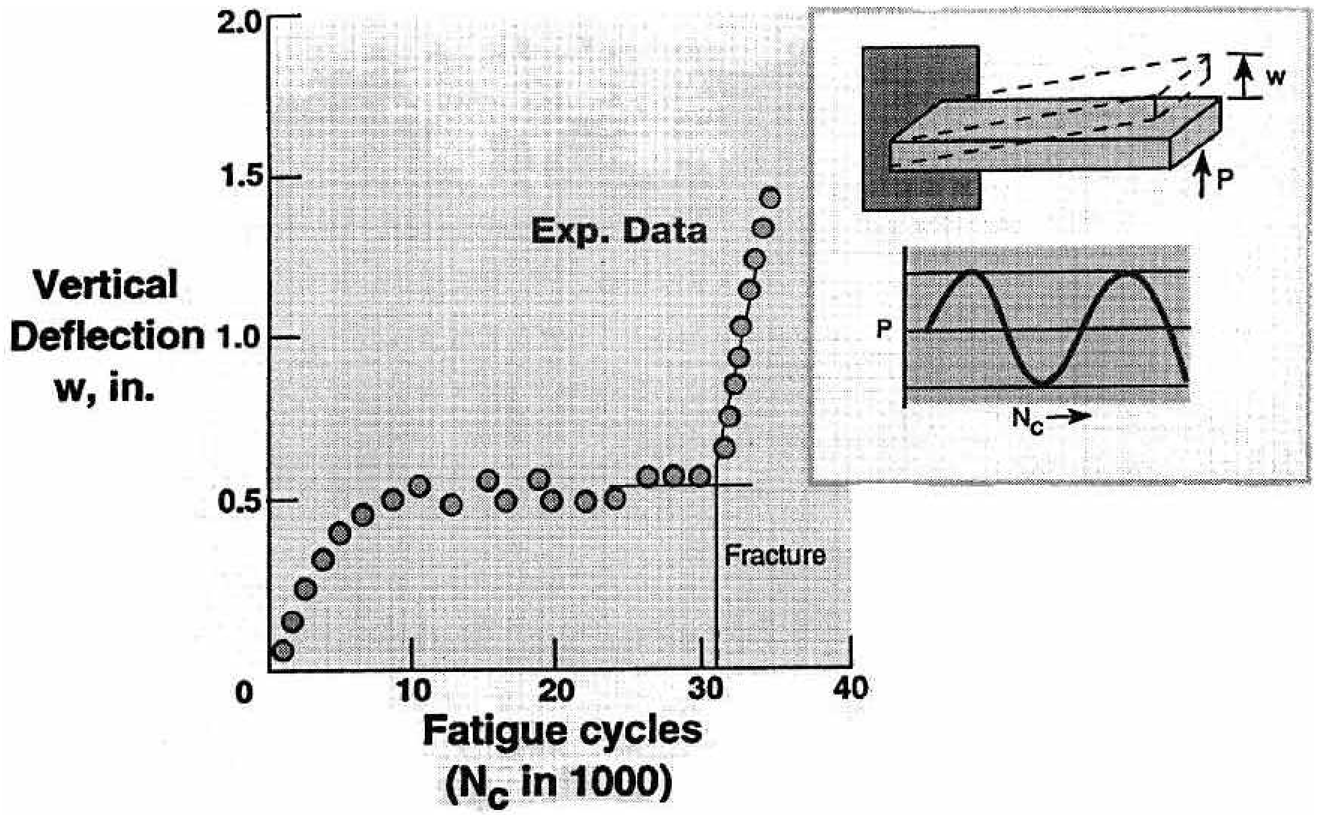
Invited Presentation for Innovative Solutions to Challenging Problems
NASA Workshop on FEM & FEA
Goddard Space Flight Center
Greenbelt, MD - May 18, 2000

Presentation Outline

- Background
- Objective
- Approach
- Applications
  - Composite panel fracture
  - Composite shell-burst
  - Composite containment
  - Composite pre-forms manufacturing
- Summary

Progressive Fracture Under Cyclic Load

(Experimental Data: Mandel, et al)



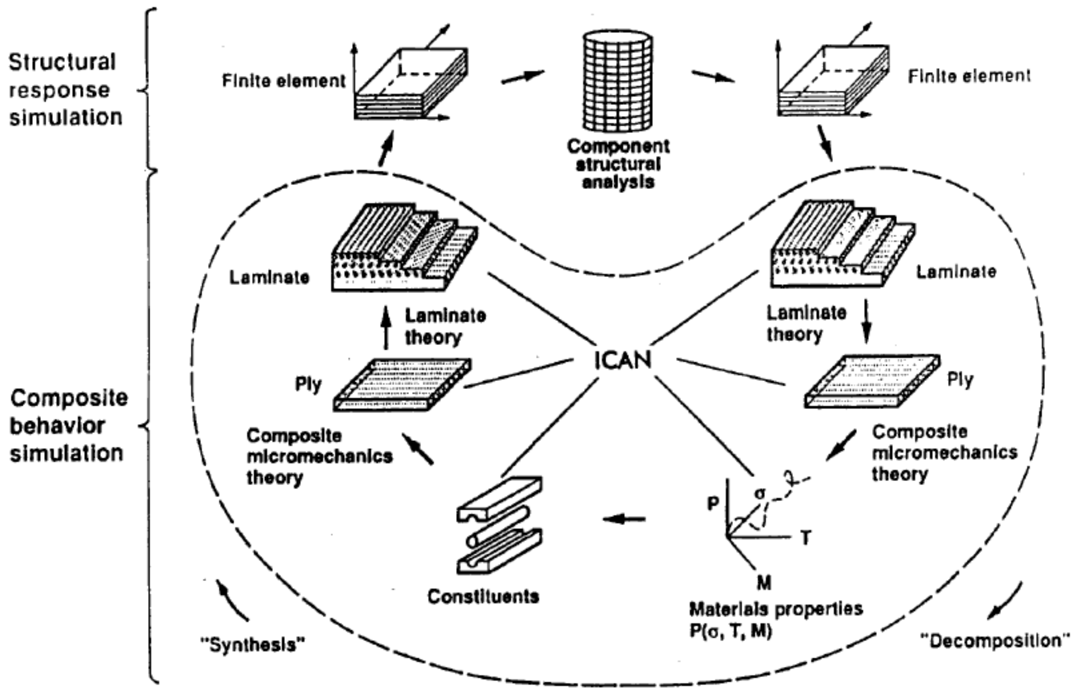
Objective

- Describe a non-traditional computational simulation method/computer code to a variety of non-linear structural responses

What is This Non-Traditional Computational Method?

- Bottoms-up synthesis for structural behavior/response
  - Telescoping composite mechanics
- Top-down decomposition for local effects
  - Progressive substructuring
- Nodal-base finite element formulation
- Progressive structural fracture
  - Incremental linear updating
  - Multi-factor interaction material behavior model
  - Node(s) - by - node(s) un-zipping
- Integrated into a seamless computer code (CODSTRAN)

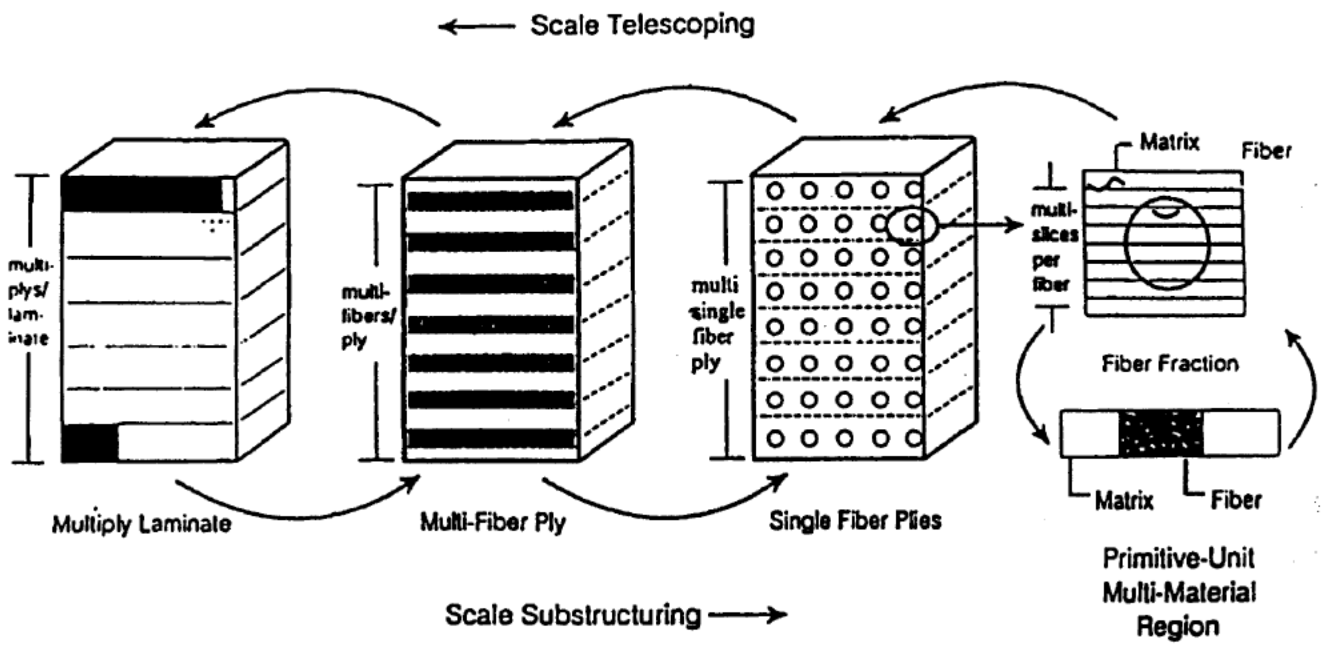
<u>CO</u>MPOSITE <u>D</u>URABILITY <u>STR</u>UCTURAL <u>AN</u>ALYSIS (CODSTRAN)

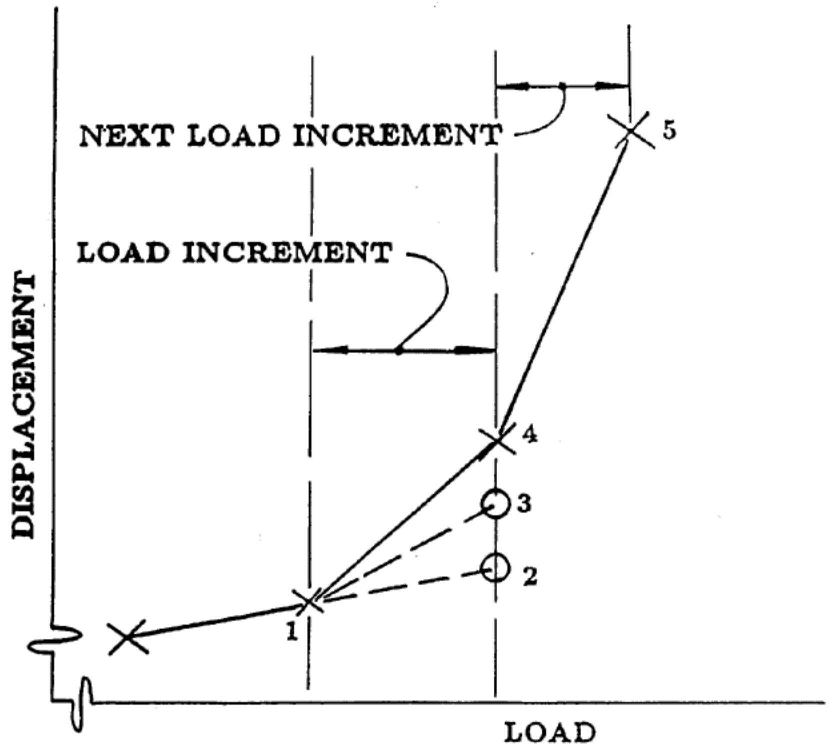


- Progressive Fracture in Composite Laminates and Structures Simulation Cycle via CODSTRAN

Multi-Scale Hierararachical Simulation

Computational Simulation: Recursive A;;lication of Laminate Theory





CODSTRAN Damage Tracking - Representative Points

1. Equilibrium - no damage
2. Initial damage: degrade properties
3. Damage accumulation: more degradation
4. Damage stabilization: no additional damage
5. Damage propagation

Composite Structural Performance Evaluation Summary

- Structural Analysis Model (SAM)

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{F(t)\}$$

- Where:

$$[M],[C],[K]=F\left(x_i,T,M,t,(E,r,s,y)_{f,m}\right)$$

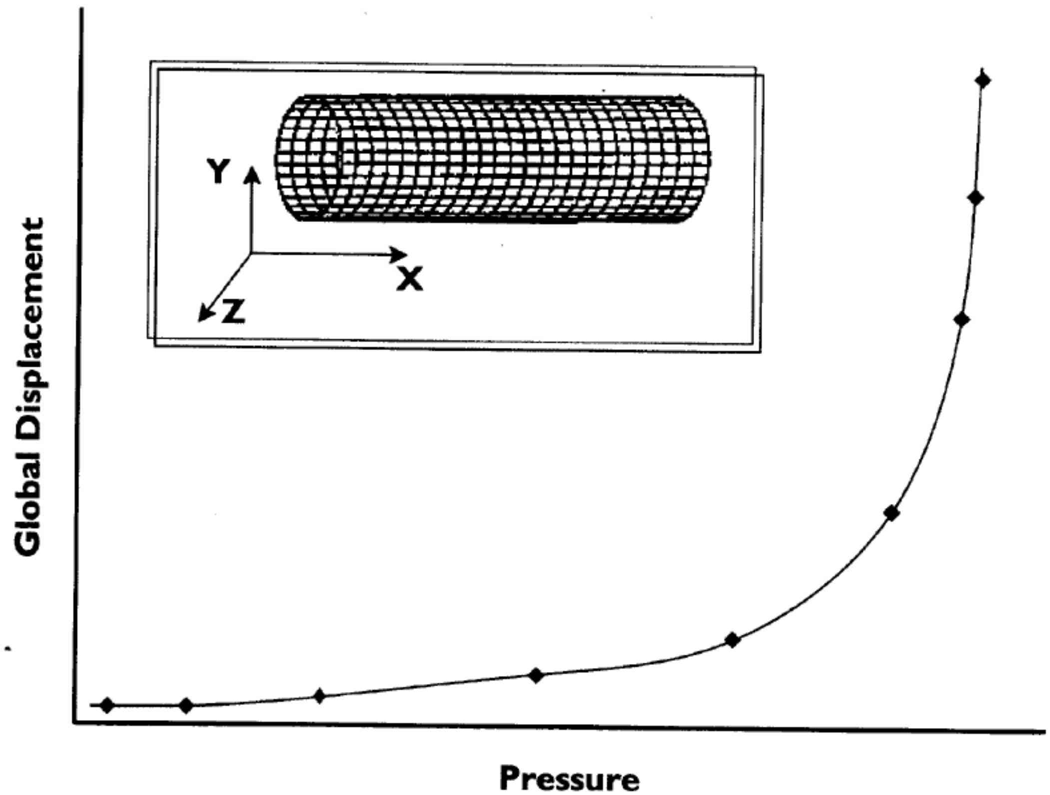
$$\{F\}=F\left(x_i,F_{m,T,M}\right)$$

- Solution of SAM:

$$u,w,P_{cr},s,G,\left(\frac{\Delta a}{N}\right)$$

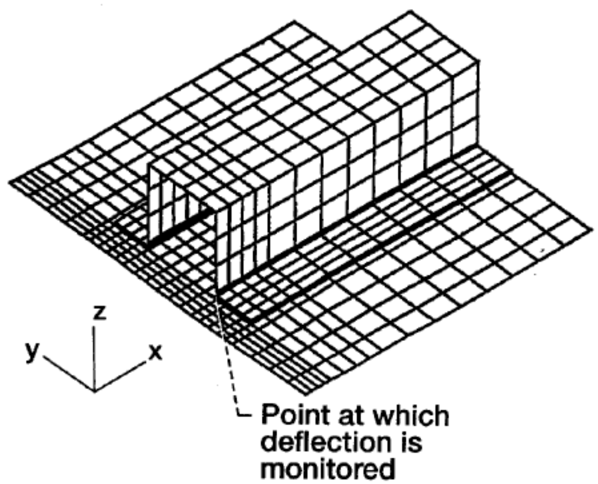
- Structural Integrity
- Fatigue and Life
- Structural Durability
- Structural Reliability

Overall CODSTRAN Simulation



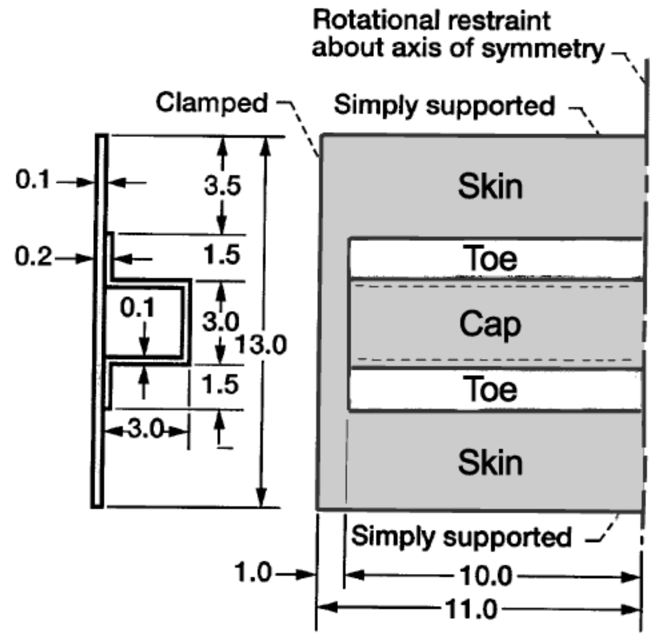
Stiffened Composite Panel

Finite-element model

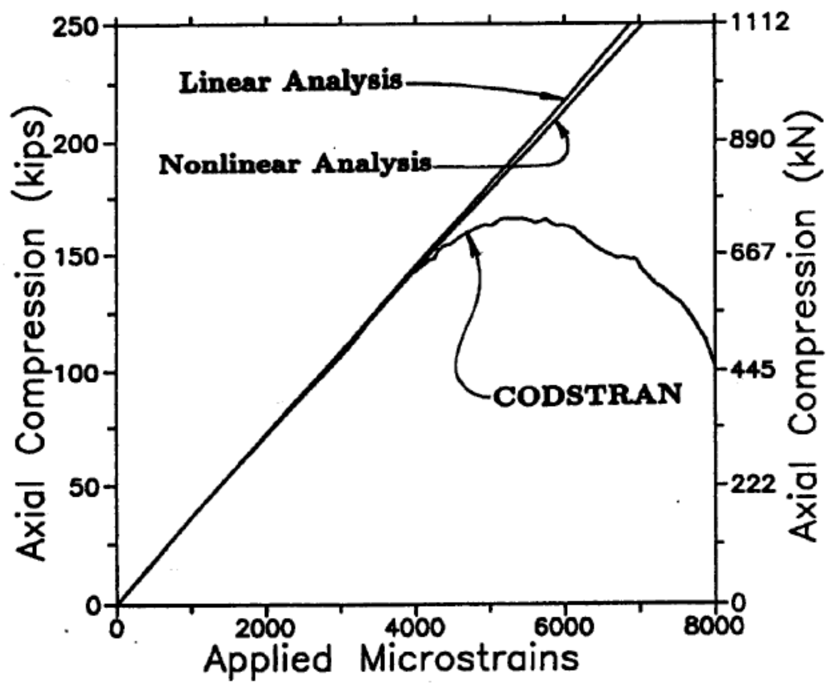


Material, IM–7/5250–4; plies, 16; configuration, [0/±45/90]s2
All dimensions are in inches.

Cross section and plan



Compressive Load with End Displacement
AS-4/HMHS$[[0/\pm45/90]_s]_6$



Predicted and Measured Ultimate Loads for Compression Tests

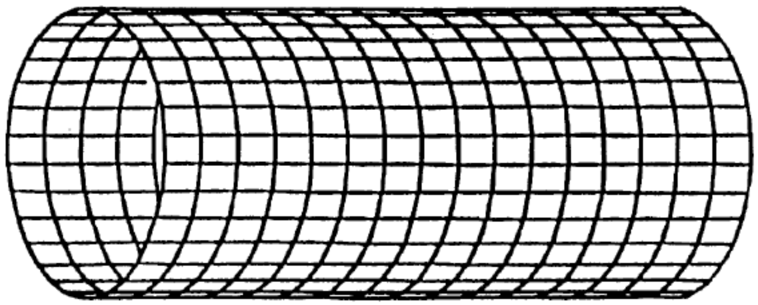
Test Case (ID Number)	**Percent Void Used**	**Predicted Ultimate Load (kips)**	**Measured Ultimate Load (kips)**
I (DSD 23C-5)	0.9	291	294
II (DSD 23C-6	0.9	238	226.6
III (DSD 23C-7	1.15	270	272.5
IV (DSD 23C-8)	1.15	199	206.8

Pressurized Cylindrical Shells

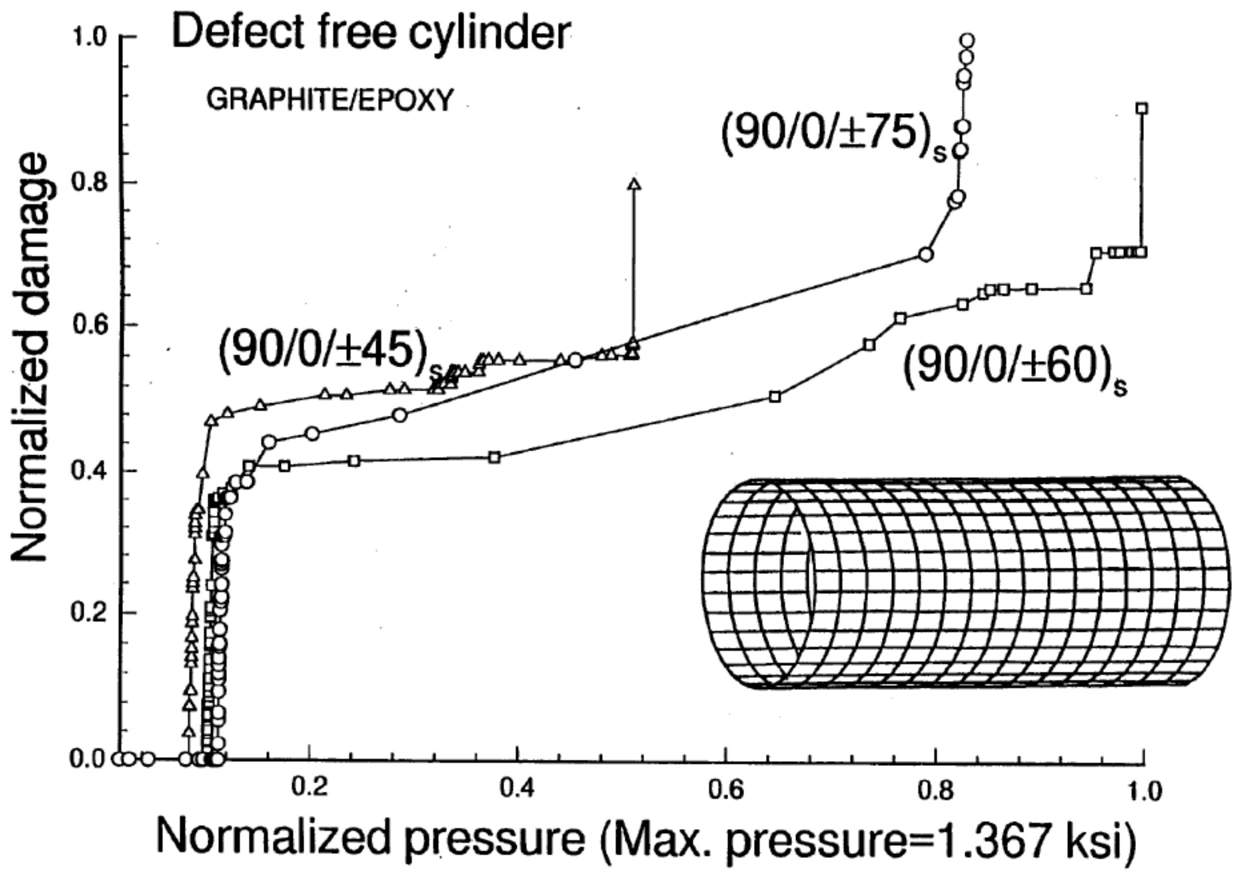
Graphite/epoxy laminated composite

$V_f = 0.60$; $V_v = 0.01$; $T_{cu} = 177°C\ (350°F)$

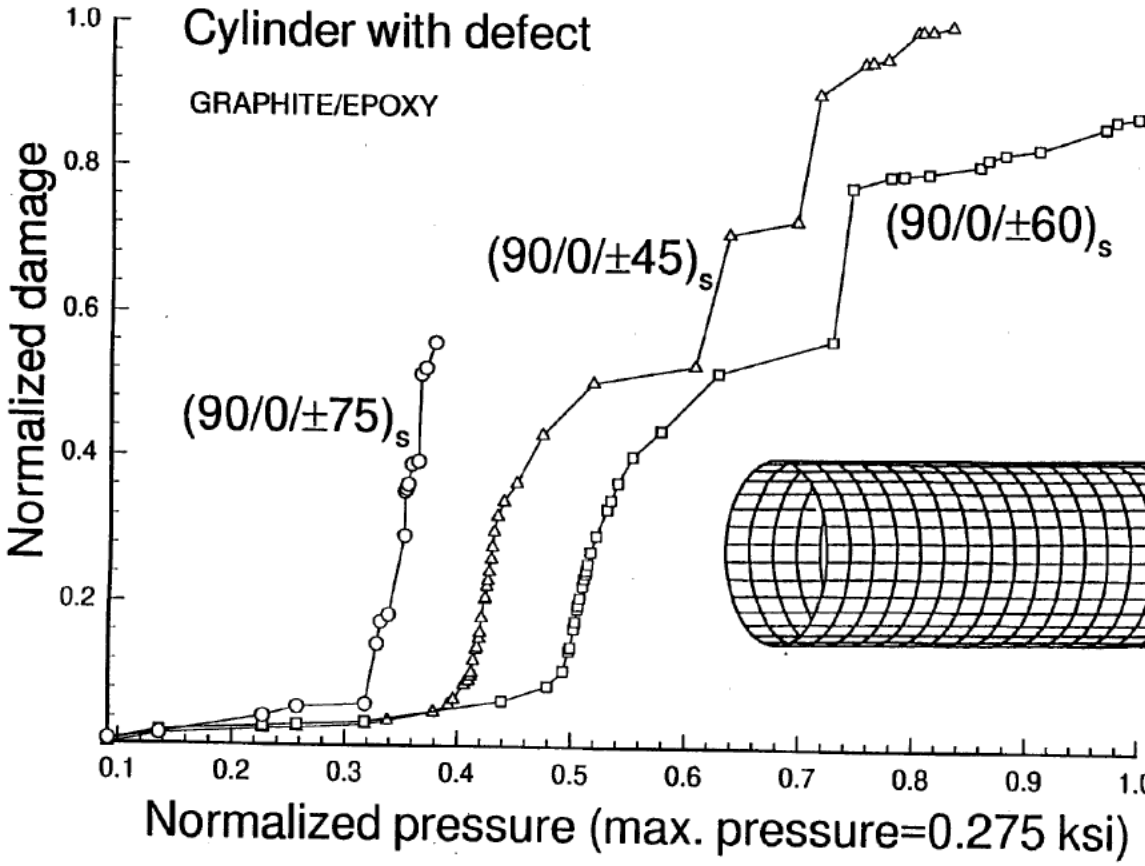
- In all cases damage initiation was my matrix cracking due to transverse tensile stresses in 0° plies.
- For the defect-free shells, fiber fractures did not occur until the burst pressure was reached.



Damage Progression With Pressure



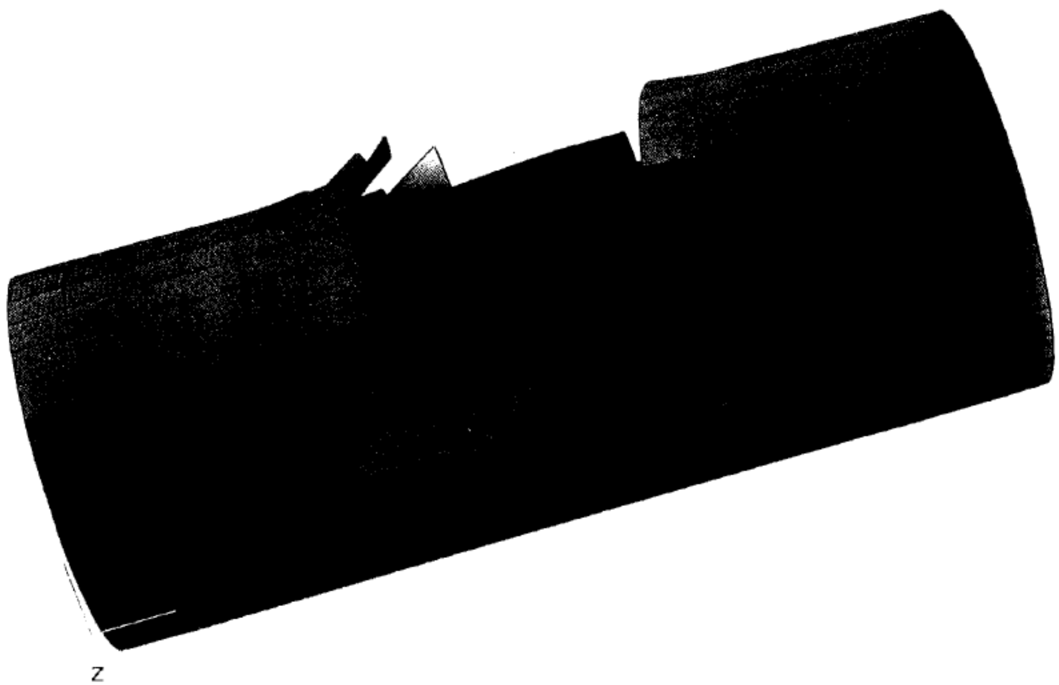
Damage Progression With Pressure



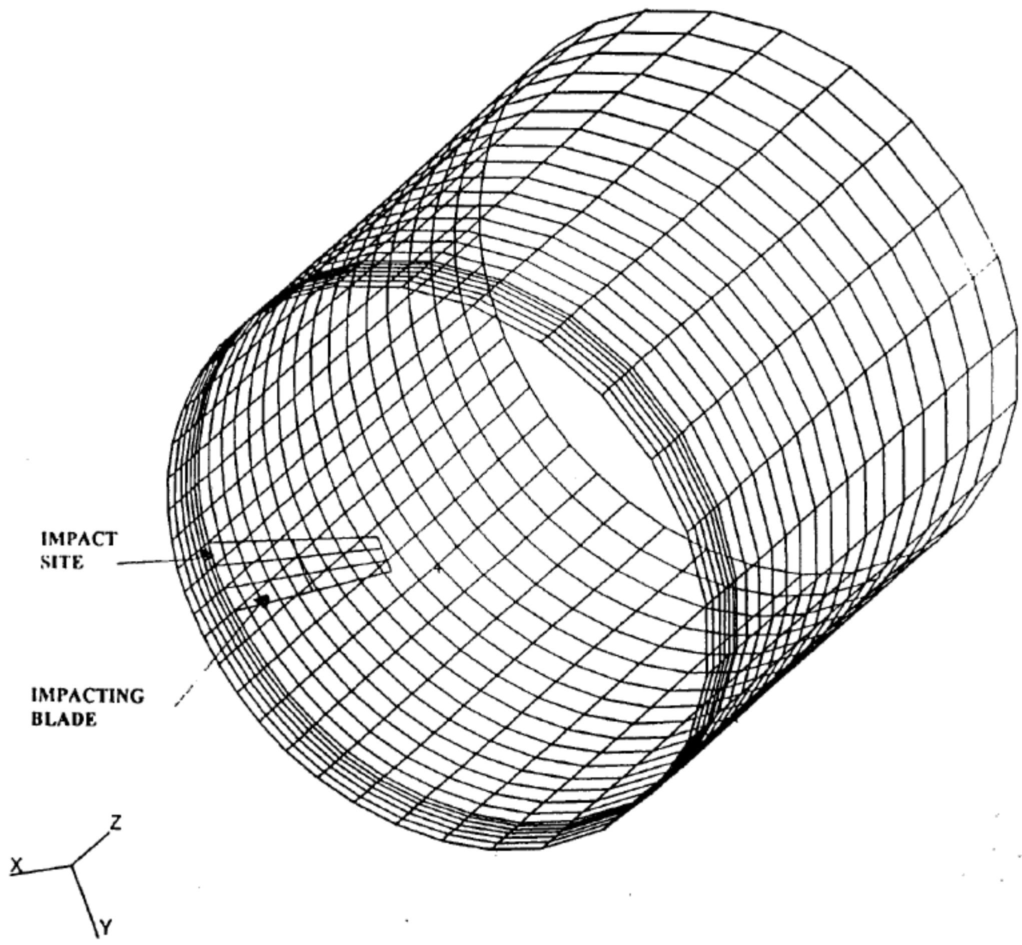
Composite Shell Burst Pressure (PSI) Summary

Laminate	No Defect	With Defect
$[90/0/\pm45]_s$	690	230
$[90/0/\pm60]_s$	1360	275
$[90/0/\pm75]_s$	1130	100

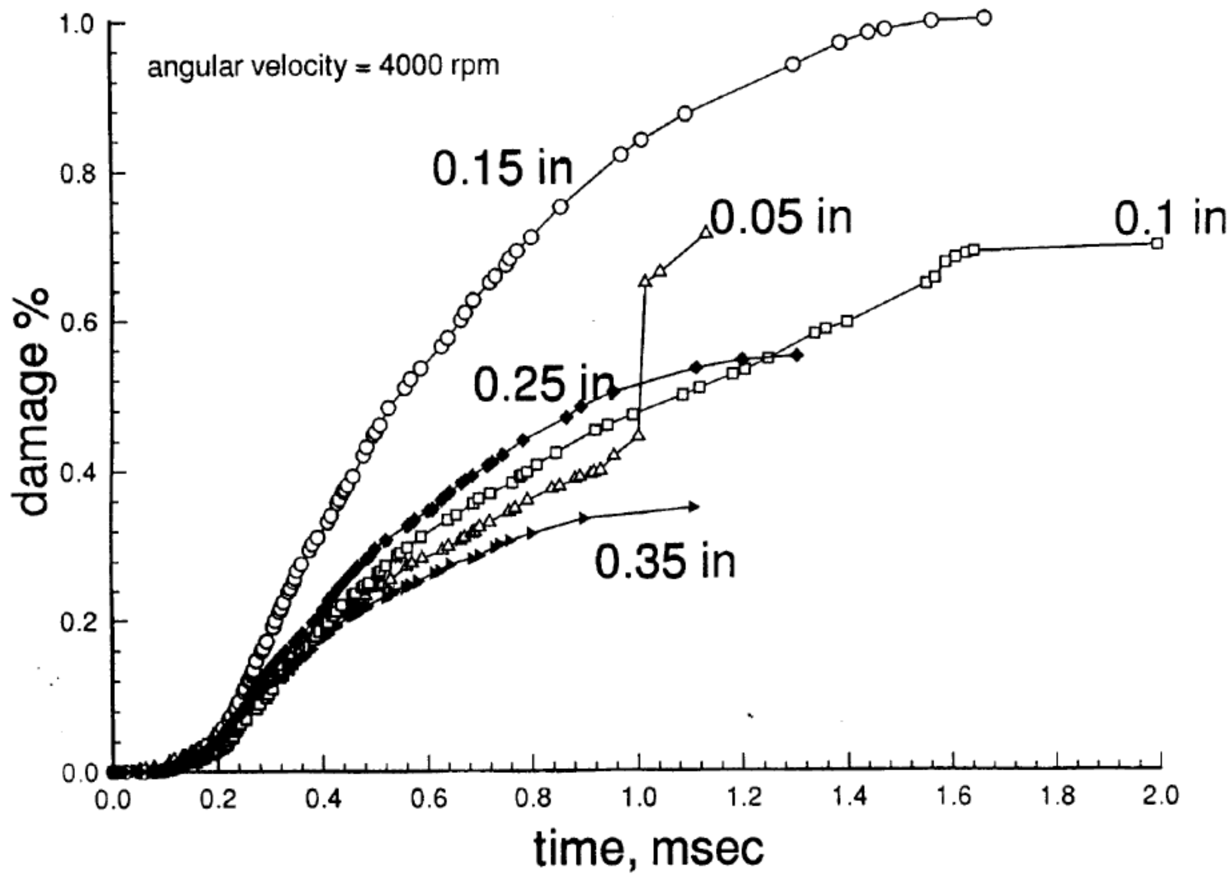
Failure of the (90/0/+75/-75)s Laminate at 104psi



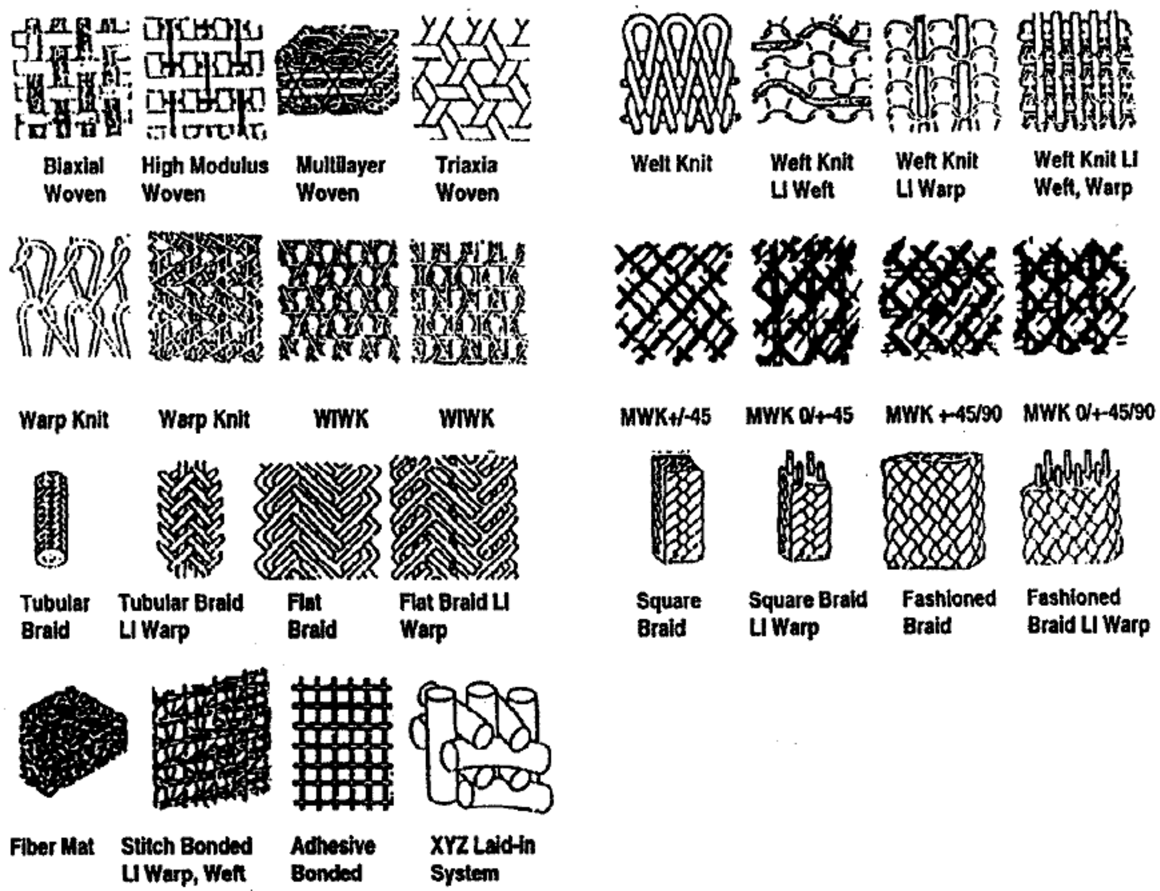
Composite Containment Structure - Finite Element Model



Effect of the Shell Thickness on the Damage



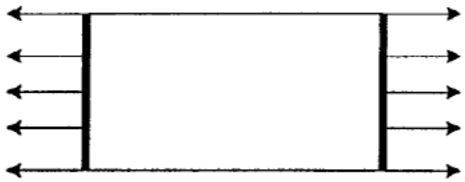
Woven, Knitted, Braided & Non-woven Fabric Structures



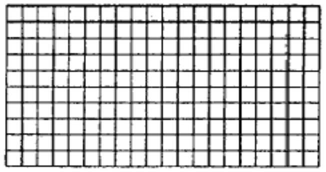
Traction Test

Traction Test of a soft matrix fiber-reinforced Composite under tension:

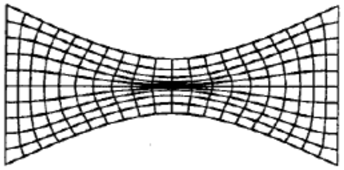
- 2 plies of initial angles +/- 50 degrees
- Initial geometry of 2 in. x 0.01 in.
- Length of the ends of the specimen do not change



Traction Test Specimen

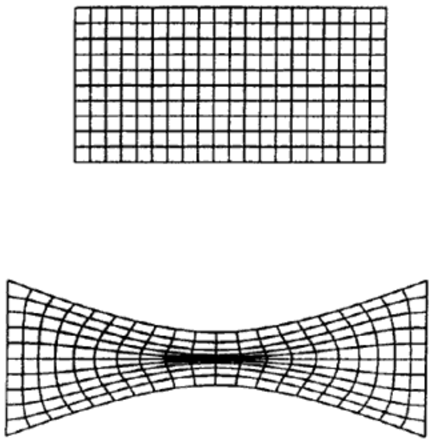


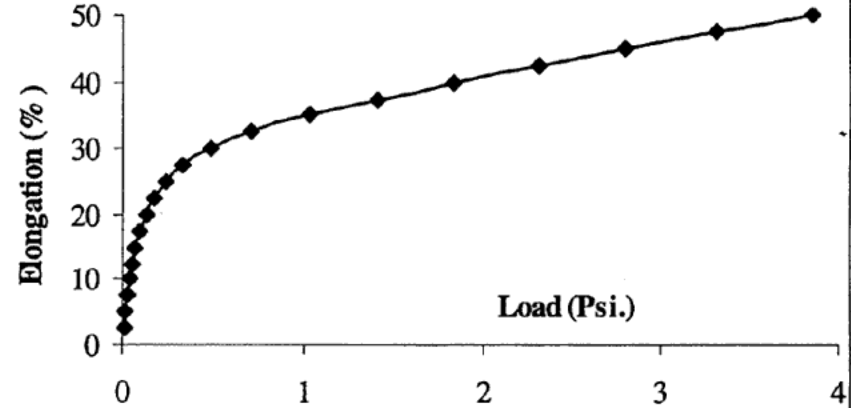
Initial Finite Element Mesh



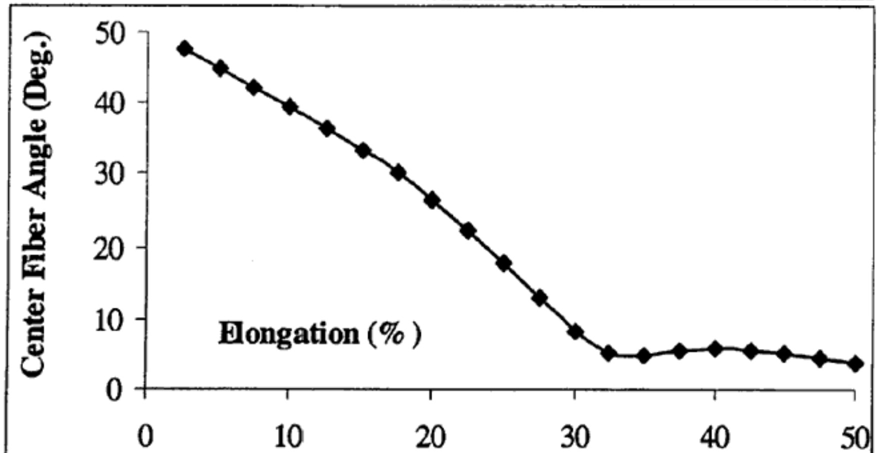
Finite Element mesh at 30% Elongation

Traction Test





Elongation at different loads

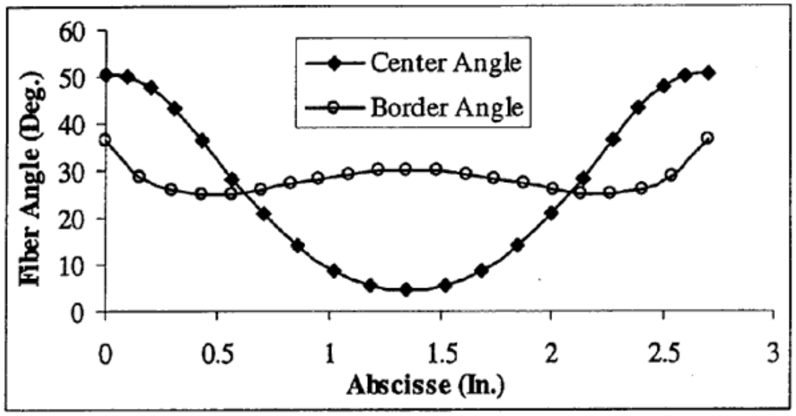


Fiber angle at the center at different global elongation

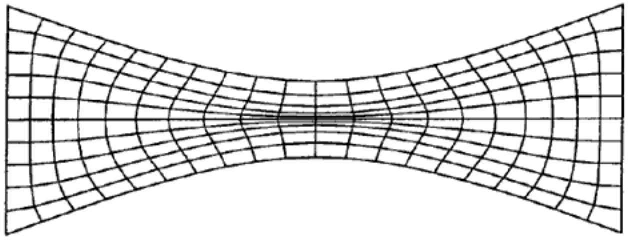
Traction Test

Remarks:

- The deformations must be monitored to prevent elongation of the fibers
- The computation of the local fiber angle provides valuable information on the process



Fiber angle at 30% elongation

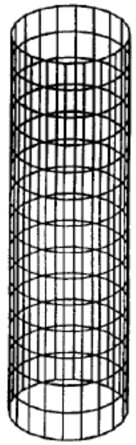


Finite Element mesh at 30% elongation

Tube Manufacturing Process Geometry

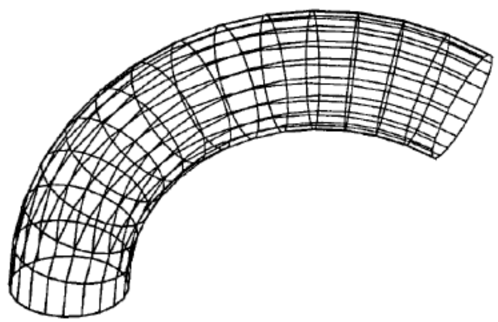
Simulation of a Tube Manufacturing Process:

- Cylindrical fiber weaves and mold of same diameter
- The bases are fixed to coincide with each other



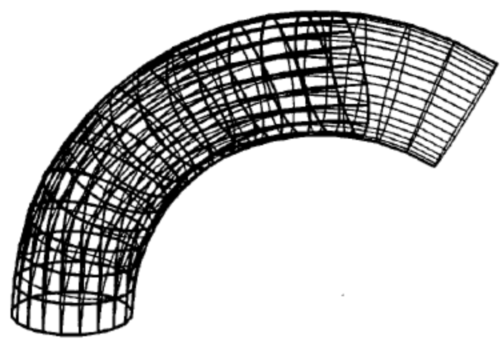
Fiber Weaves:

Cylinder of 5 in. diameter and 18 in. long



Mold:

Bent Cylinder of 5 in. diameter and radius of curvature of 11 in.



Result:

Fiber Weaves fitted over the mold

Summary

- A non-traditional computational simulation method with a seamless computer code for non-linear structural response/behavior was described
- It is bottoms-up synthesis; top-down decomposition with incremental linear updating
- Its versatility was demonstrated by presenting simulating results from
  - Composite panel fracture
  - Composite burst
  - Composite containment
  - Composite pre-forms manufacturing
- The method/computer code is unique
  - Only one of its kind